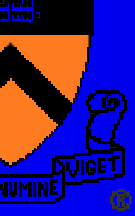


# **The Adverse Impact of Surface Ozone on Agricultural Crops**

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Air Pollution as a Climate Forcing workshop  
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# Outline

- ★ Motivation
- ★ O<sub>3</sub> Impact on Plants
  - Mechanism
  - Effect
- ★ Crop yield reductions
- ★ Evaluation of O<sub>3</sub>-induced agricultural yield loss in East Asia.



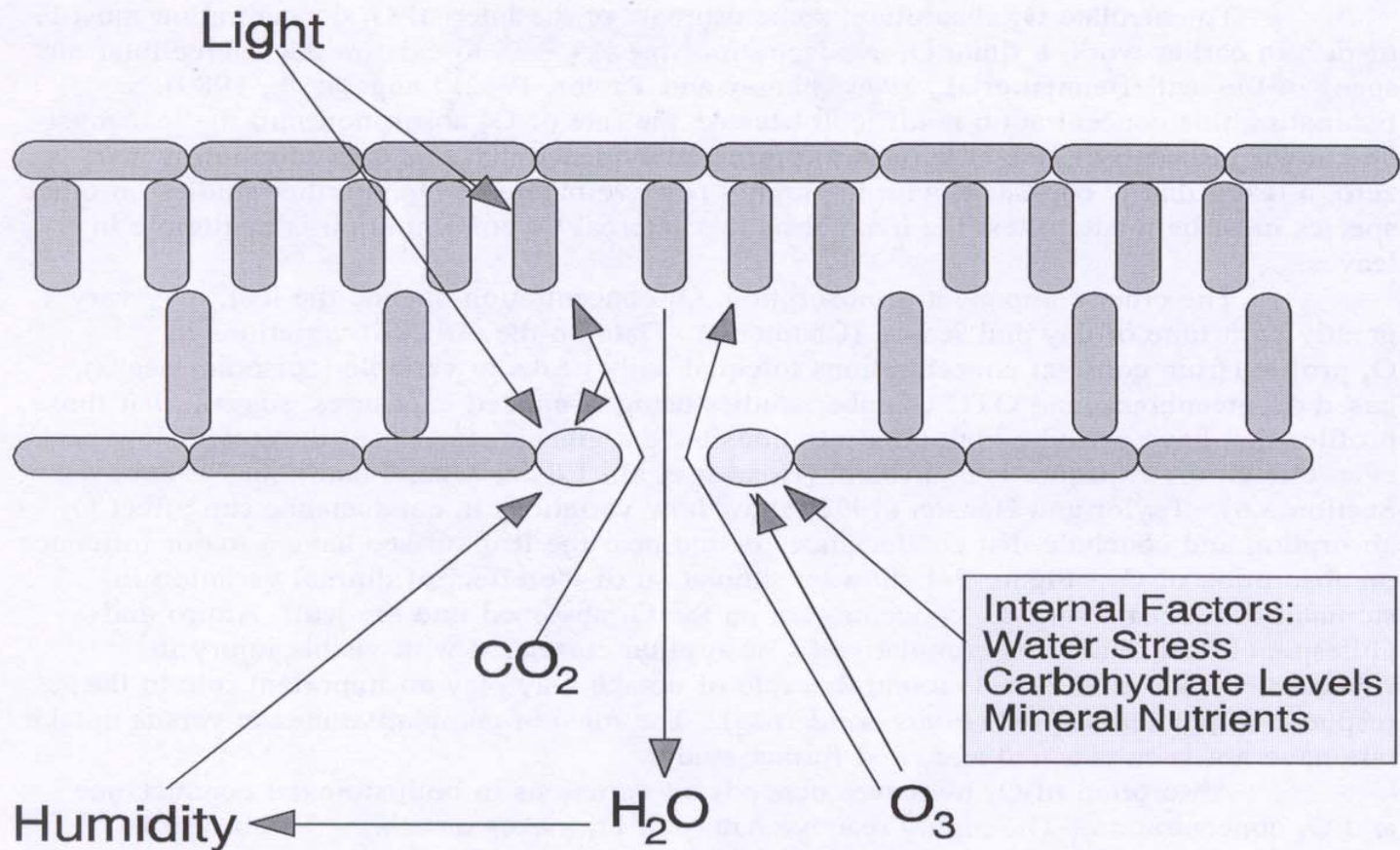
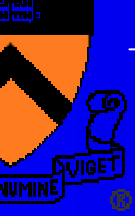
# Motivation

- $O_3$  is considered the most damaging air pollutant for plants.
- In the United States, protection of human health dominates regulatory control efforts for  $O_3$ . “Human welfare” has received little attention. As a result, secondary standards (to protect welfare) are set equal to primary standards (to protect health). Not optimal for protection of vegetation.
- In Europe, protection of natural ecosystems is a higher priority.
- In Asia, food security is a concern. Reductions in agricultural yields could result in China requiring food imports to feed its population.
- Opportunity exists to motivate developing countries to reduce their emission of air pollutants (and possibly simultaneously greenhouse gas emissions) in order to feed their people.



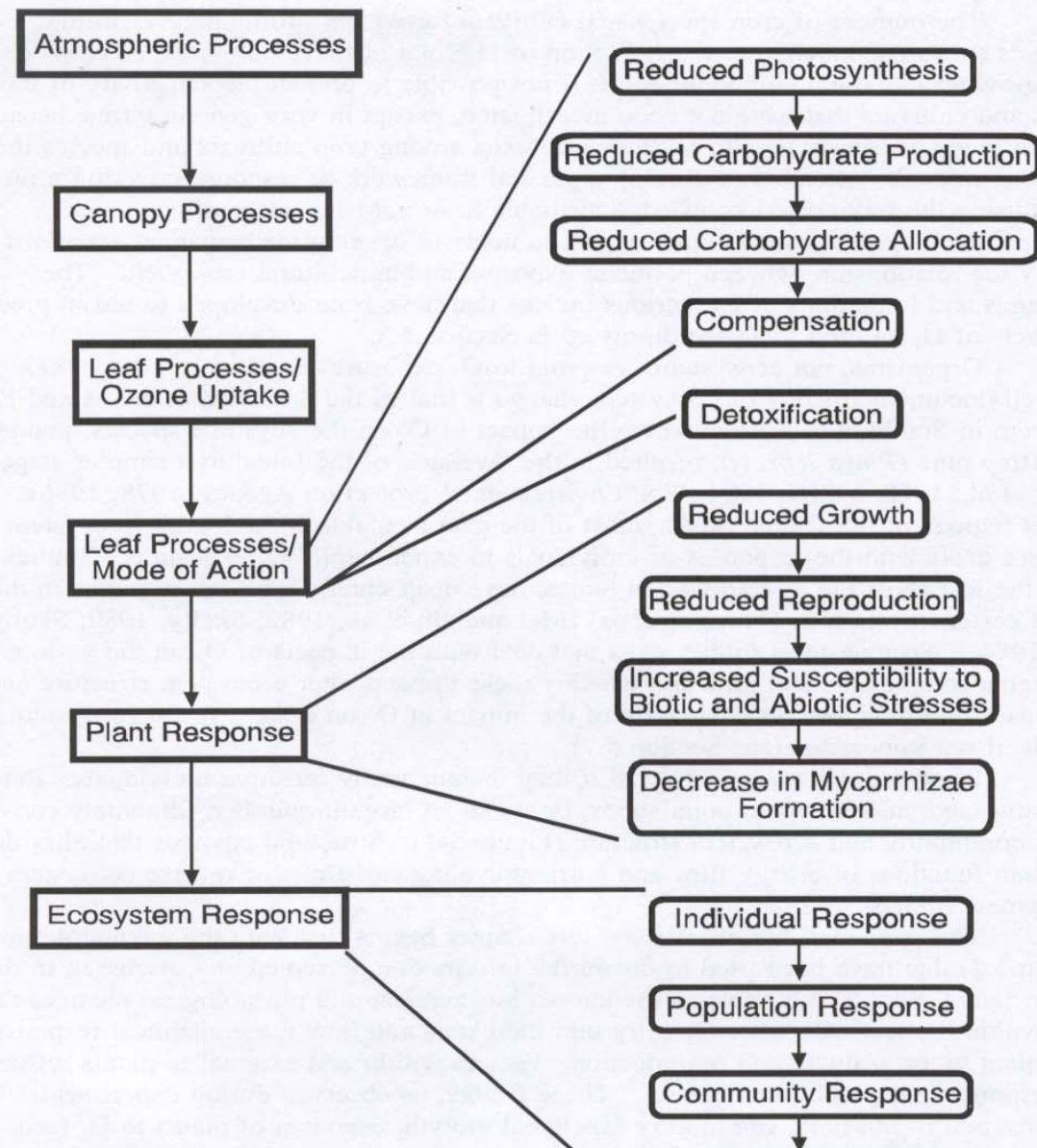
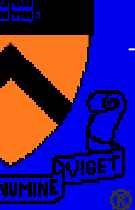
# O<sub>3</sub> Impact on Plants

- Plant processes are impaired only by O<sub>3</sub> that enters leaf through stomata (leaf opening).
- Leaf injury will not occur if O<sub>3</sub> enters slower than repair or detoxification processes take place.
- O<sub>3</sub> dose to plant will depend on a variety of environmental factors (ie. water availability, temperature, etc.).
- Different species of plant and different crop cultivars exhibit a wide range of responses to O<sub>3</sub> exposure.



**Figure 5-3.** Movement of gases into and out of leaves is controlled primarily by the stomata (small openings in the leaf surface whose aperture is controlled by two guard cells). Guard cells respond to a number of external and internal factors, including light, humidity, carbon dioxide ( $CO_2$ ), and water stress. In general, the stomata open in response to light and increasing temperature and close in response to decreasing humidity, increased  $CO_2$ , and increasing water stress. They also may close in response to air pollutants, such as ozone.







# Methods for Estimating Plant Response to $O_3$

- Peak concentration (ie. Current U.S. standard - 120 ppb for 1-hr.; new standard - 80 ppb over 8 hours).
- Seasonal mean (ie.  $O_3$  concentration over 7-hour or 12-hour daylight period over growing season).
- Cumulative exposure (ie. SUM06, AOT40).
- Cumulative exposure weighted by humidity/water availability (ie. European 'level 2' standards) to better estimate dose of  $O_3$  to plant.



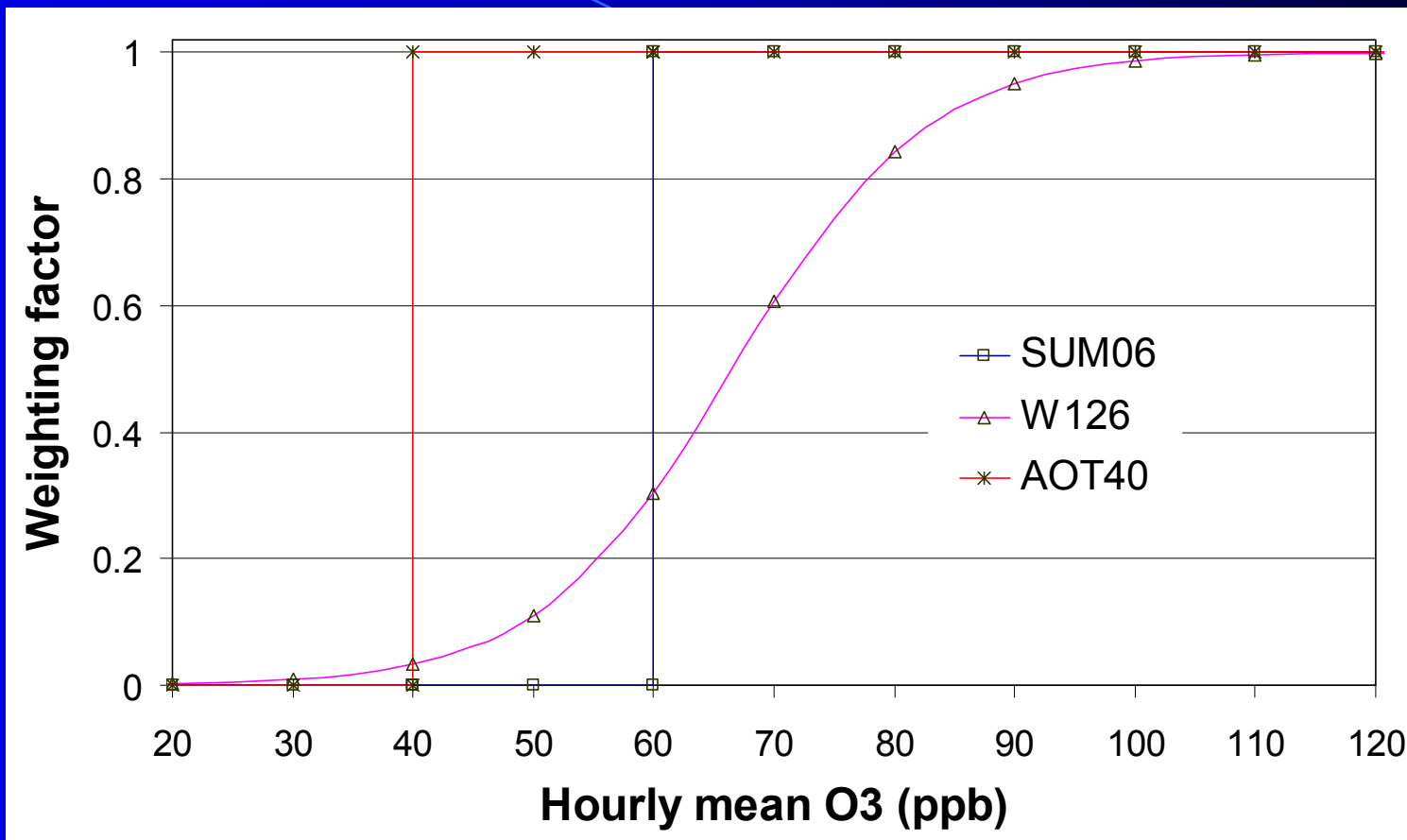
# Major Studies Examining Impact of O<sub>3</sub> on Agriculture

- U.S. National Crop Loss Assessment Network (NCLAN) study in 1980s.
  - Found peak statistics not able to predict yield reductions; seasonal mean statistics were able to predict reductions.
  - Later analysis found that an index that weighted peak concentrations and accumulated exceedances over a threshold of 60ppb gave best fit to yield reduction data.
- European Open Top Chamber (EOTC) program in 1990s.
  - Found yield reductions were correlated with cumulative exposure to O<sub>3</sub> above a threshold of 40ppb during daytime.
- Individual studies in some Asian countries, but no large-scale evaluation of local crops





# Defining Cumulative Plant Exposure to



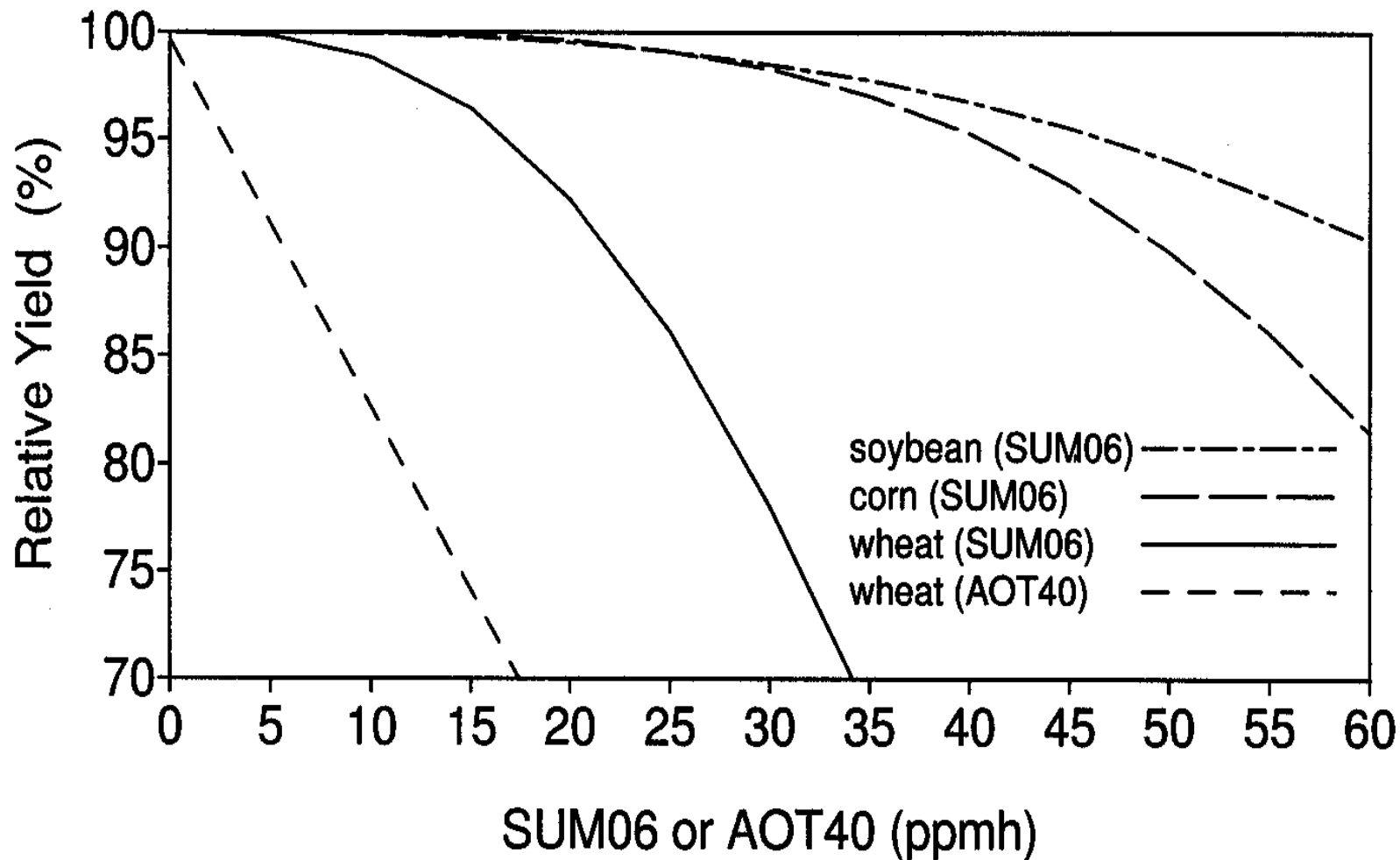
$$\text{AOT40 (ppbh)} = \sum_{i=1}^n [C_{\text{O}_3} - 40]_i \text{ for } C_{\text{O}_3} \geq 40 \text{ ppb,}$$

$$\text{SUM06 (ppbh)} = \sum_{i=1}^n [C_{\text{O}_3}]_i \text{ for } C_{\text{O}_3} \geq 60 \text{ ppb,}$$

$$\text{W126 (ppbh)} = \sum_{i=1}^n \left( \frac{C_{\text{O}_3} - 20}{51} \right)^{1.5} \text{ for } C_{\text{O}_3} \geq 20 \text{ ppb,}$$

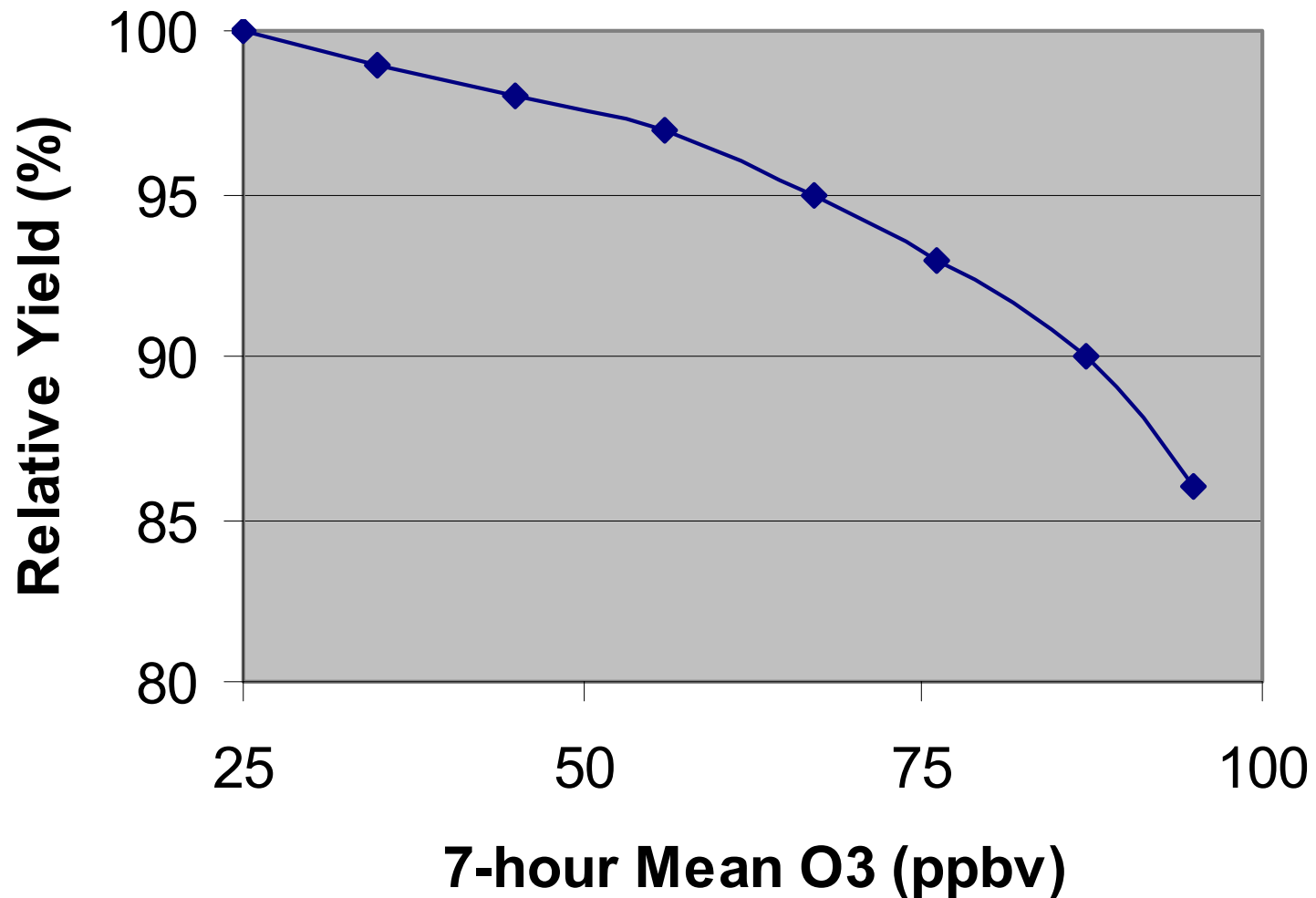


# Relative Field Losses Due to Ozone for Soybean, Corn and Wheat





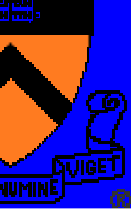
# Relative Yield Losses Due to Ozone for Rice





# Synergistic Effects

- Enhanced  $\text{CO}_2$  concentrations appear to partially ameliorate damage caused by enhanced  $\text{O}_3$  concentrations.
- Soil moisture stress reduces  $\text{O}_3$ -induced yield loss because plants close stomata to conserve water.
- $\text{O}_3$  stress appears to increase susceptibility of crops to pests.



# Analysis of the Impacts of O<sub>3</sub> on Agriculture in East Asia

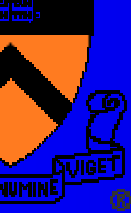
- ❶ East Asia has 23 % of the world's population, consumes 12% of the world's energy, and includes China as the world's largest agricultural producer.
- ❷ High population growth and increasing energy consumption is causing worsening air pollution in East Asia.
- ❸ “Who will feed China?” is a serious future concern.
- ❹ Few studies have been conducted to look at the impact of air pollution on agriculture in this region. However, relationships between surface ozone and crop yield loss have been established in the U.S. and Europe.
- ❺ Our objective is to quantify the impact of surface ozone on grain production, and to examine how successful air pollution control could prevent a decrease in agricultural production.



# Method

- Use MOZART-2 (global chemical tracer model) to determine surface  $O_3$  concentrations in East Asia.
- Use  $O_3$  concentrations over growing season for each crop to determine exposure.
- Use dose-response functions obtained in U.S. and European studies to estimate yield reductions.
- Estimate economic value of crops lost.
- Conduct sensitivity analysis of gains/losses in yield resulting from a 25% decrease/increase in  $O_3$  concentrations.





# MOZART-2 GLOBAL MODEL OVERVIEW

**Resolution:** 2.8° lat x 2.8° long; 34 hybrid vertical levels (surf.– 5 mb).

**Timestep:** 20 minutes for all processes.

**Winds:** offline climatological winds (MACCM3).

**Photochemistry:** 58 chemical species, 132 kinetic + 31 photolysis reactions.

**Surface emissions:**

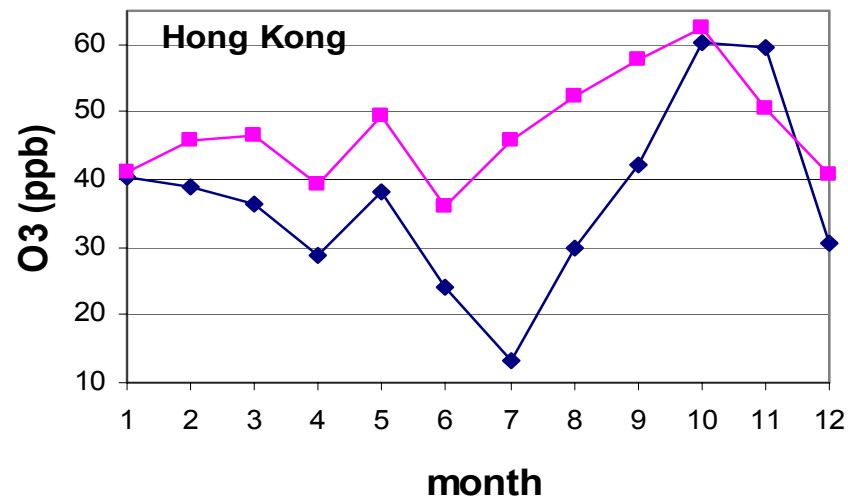
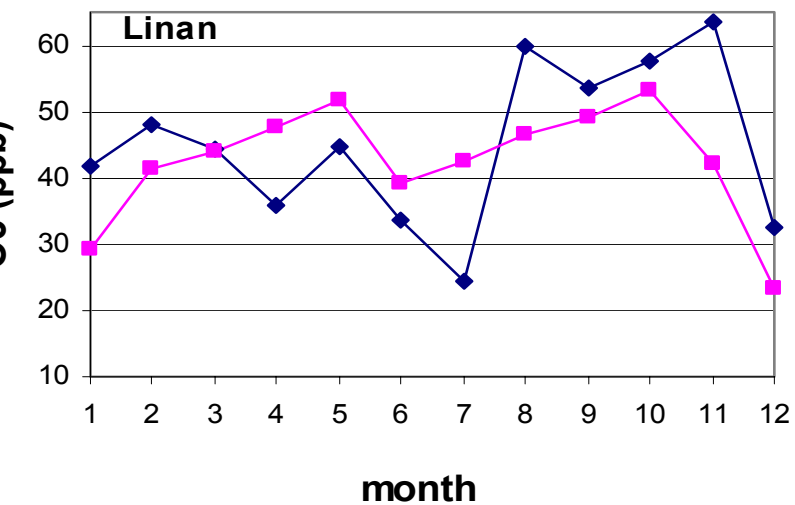
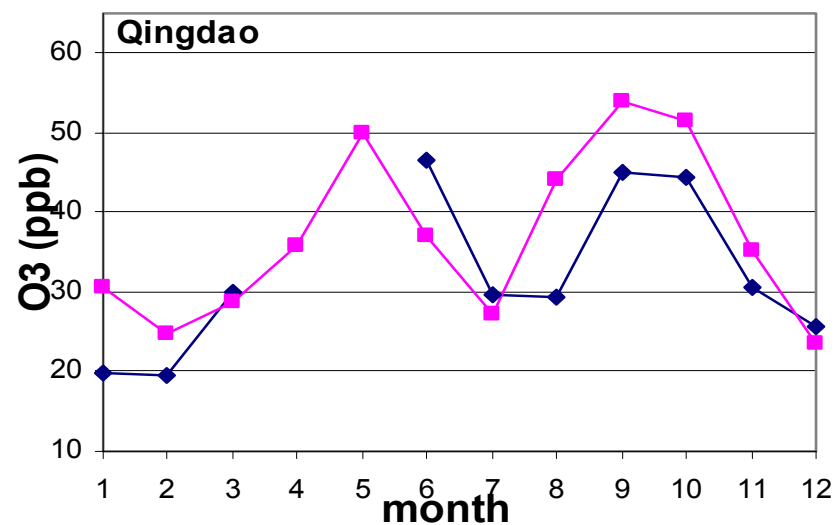
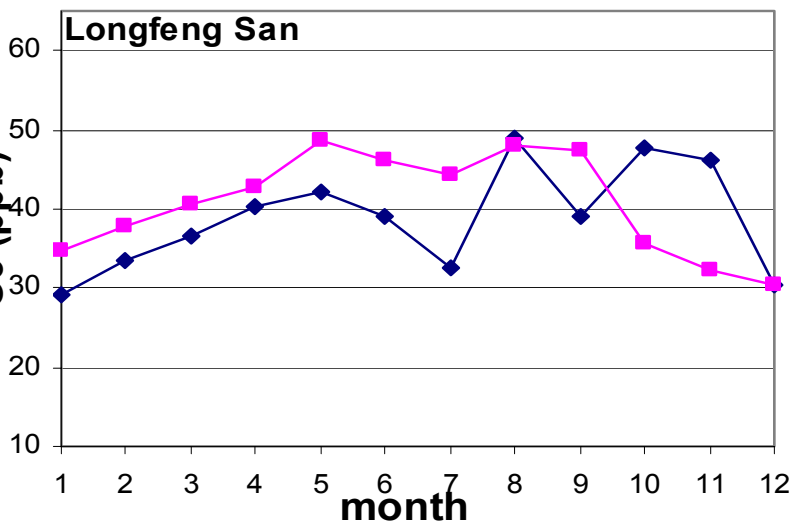
- **Anthropogenic fossil fuel combustion**
- **Biomass burning**
- **Biogenic emissions**
- **Soil emissions**
- **Oceanic emissions**
- **Lightning:** NO<sub>x</sub> source in convective clouds

**Advection**

**Convection**

**Dry and wet deposition**

(8am-8pm)

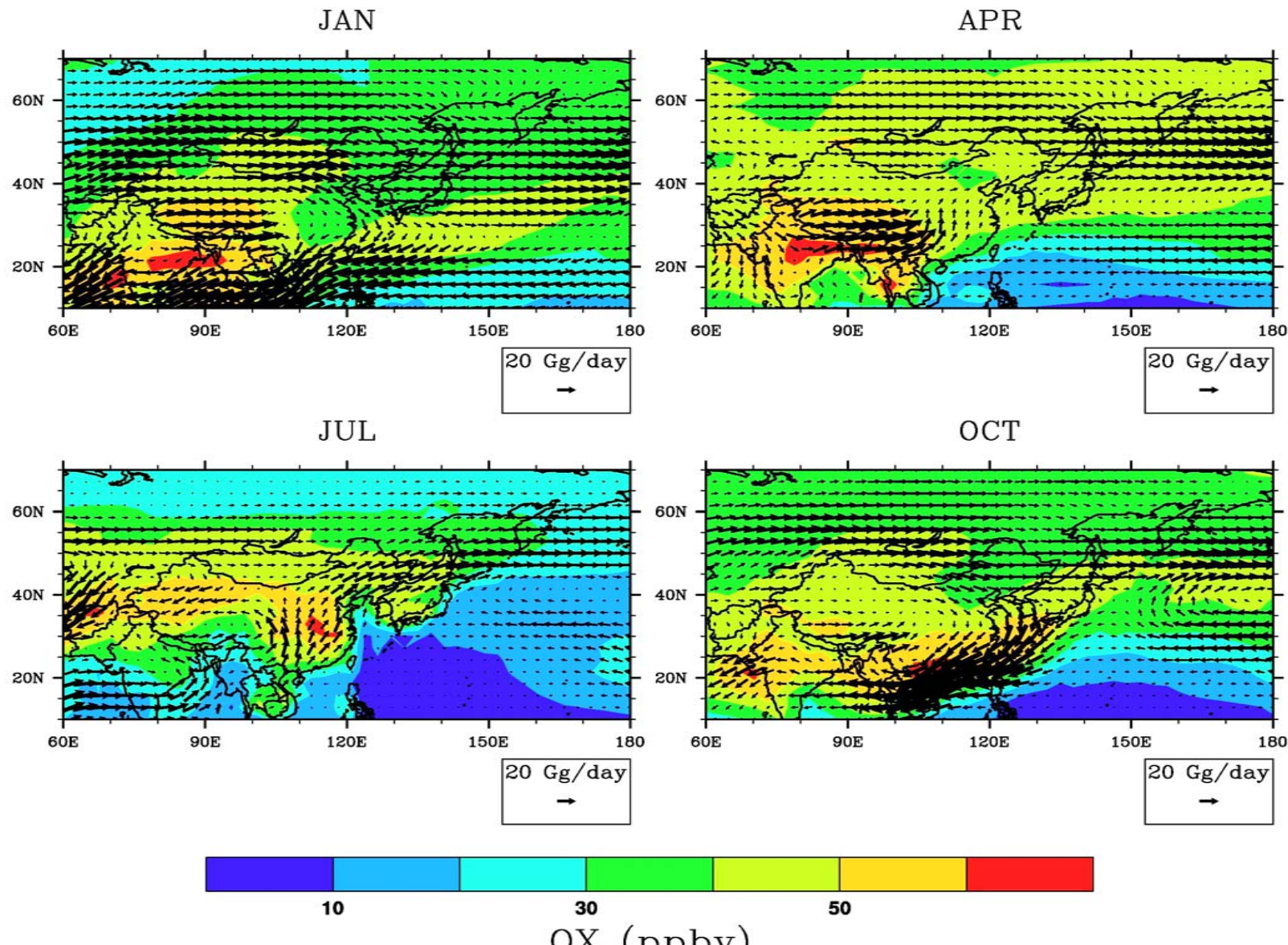


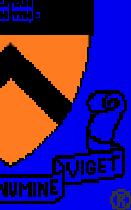
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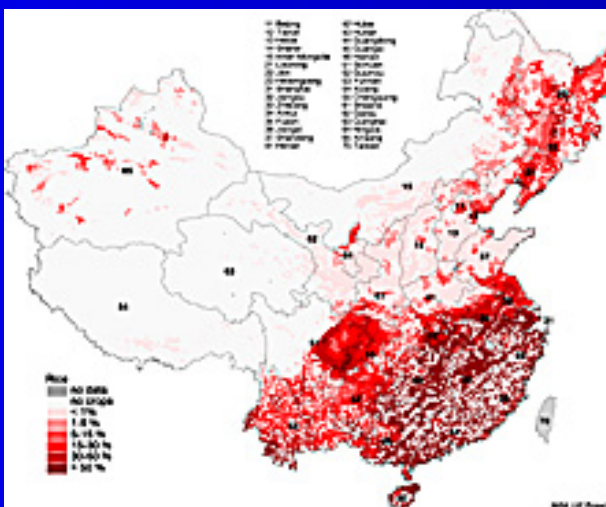


# Boundary Layer $O_3$ Concentrations and Horizontal Fluxes

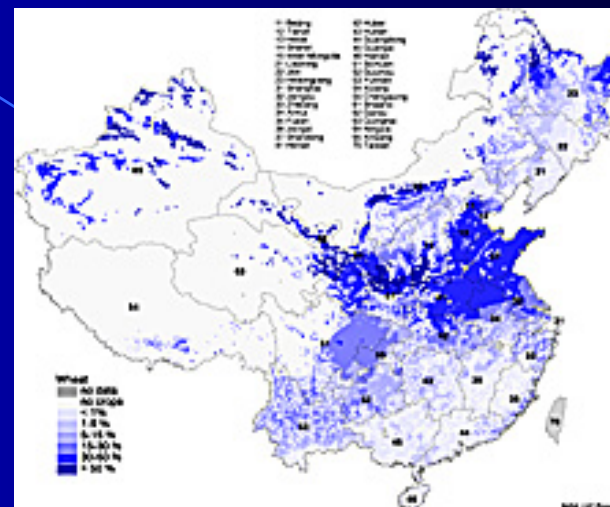




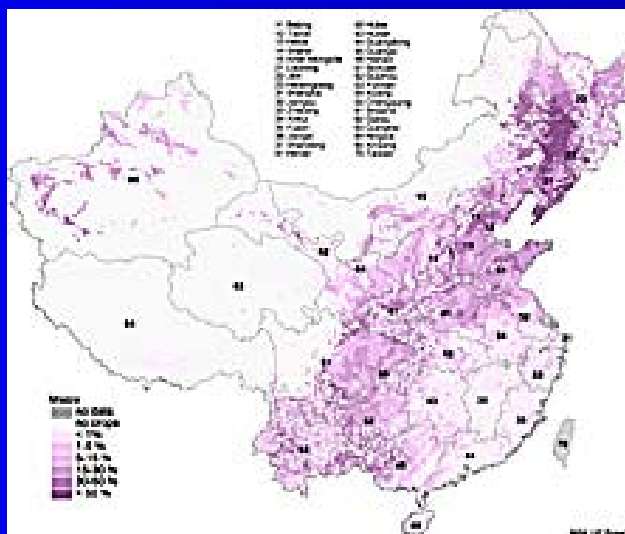
# in China



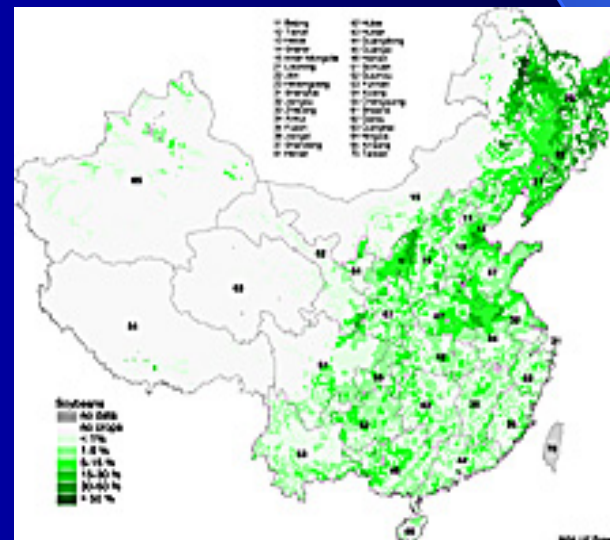
Rice



Wheat

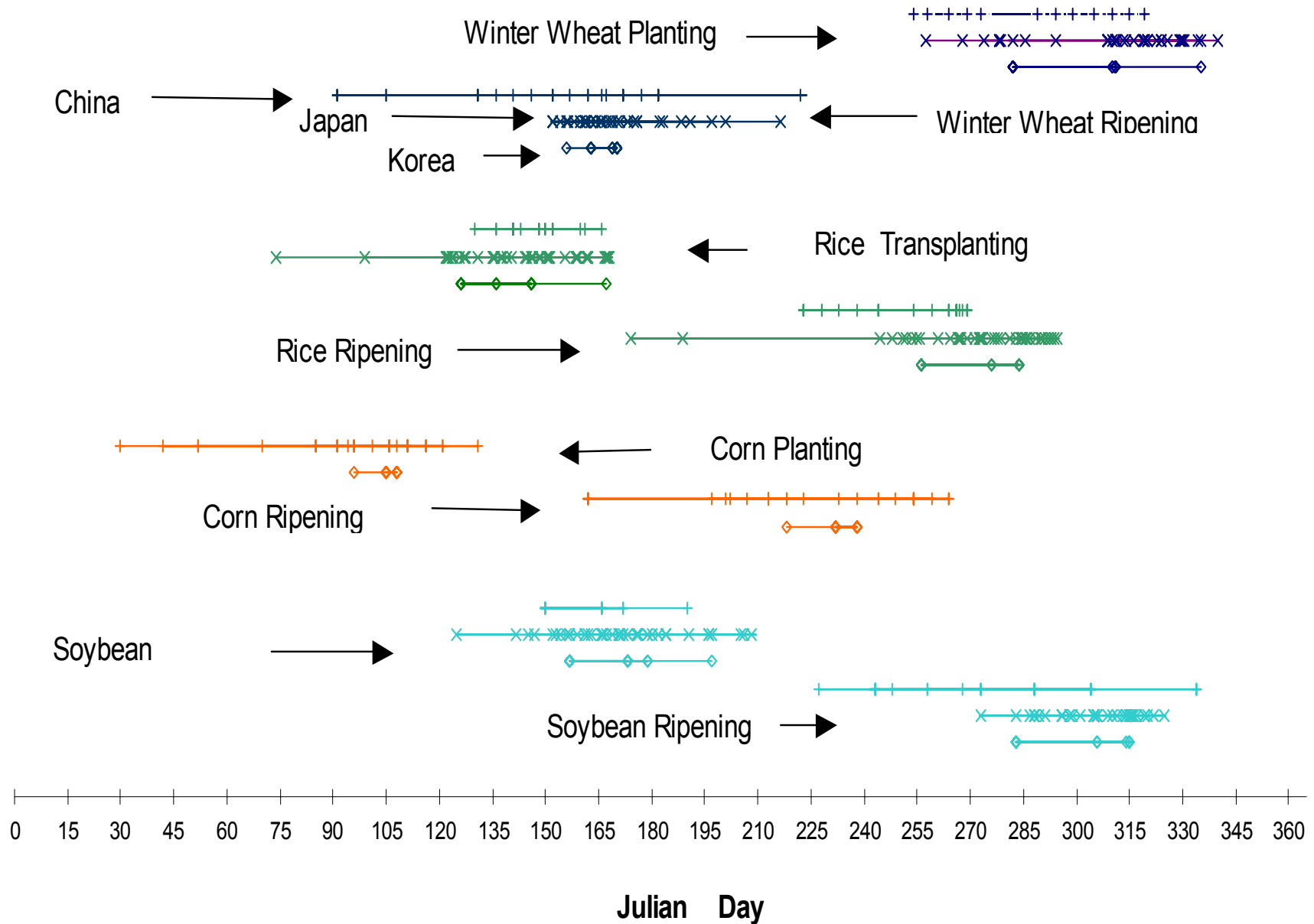


Corn



Soybeans

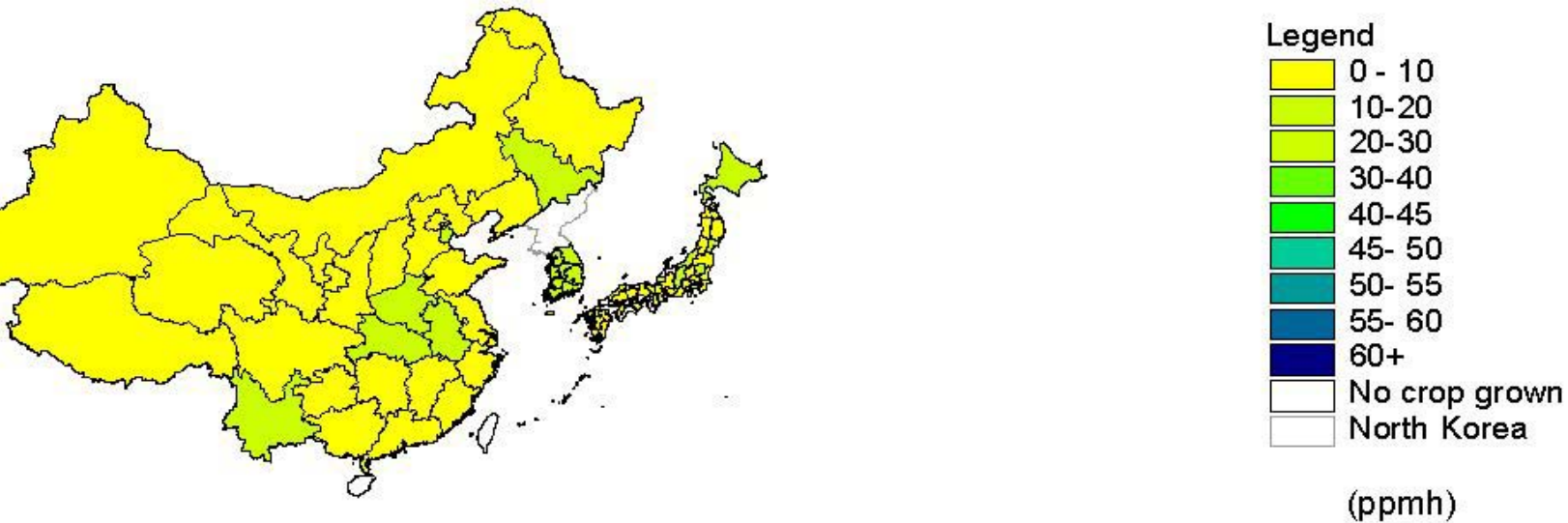
# Growing seasons for winter wheat, single-crop rice, spring corn and soybeans in China, Japan and South Korea



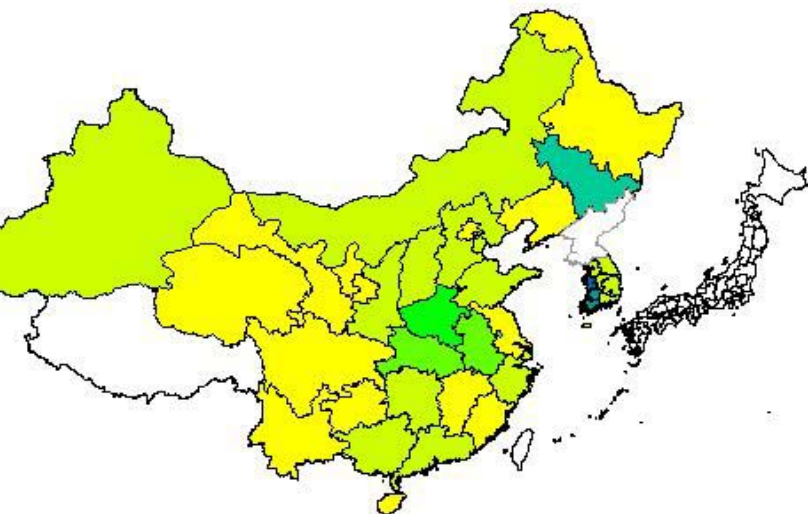
Note: For a group of three lines, from top to bottom are China, Japan and Korea; for a group of two lines, the top line is for China, and the bottom line is for Korea.



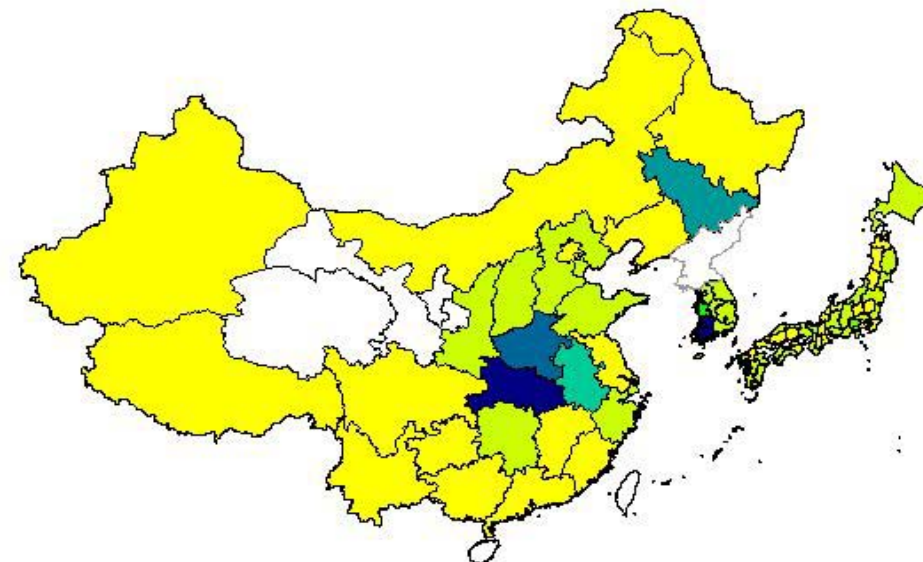
# 24-h SUM06 Distribution for Various Crops in East Asia



Winter Wheat



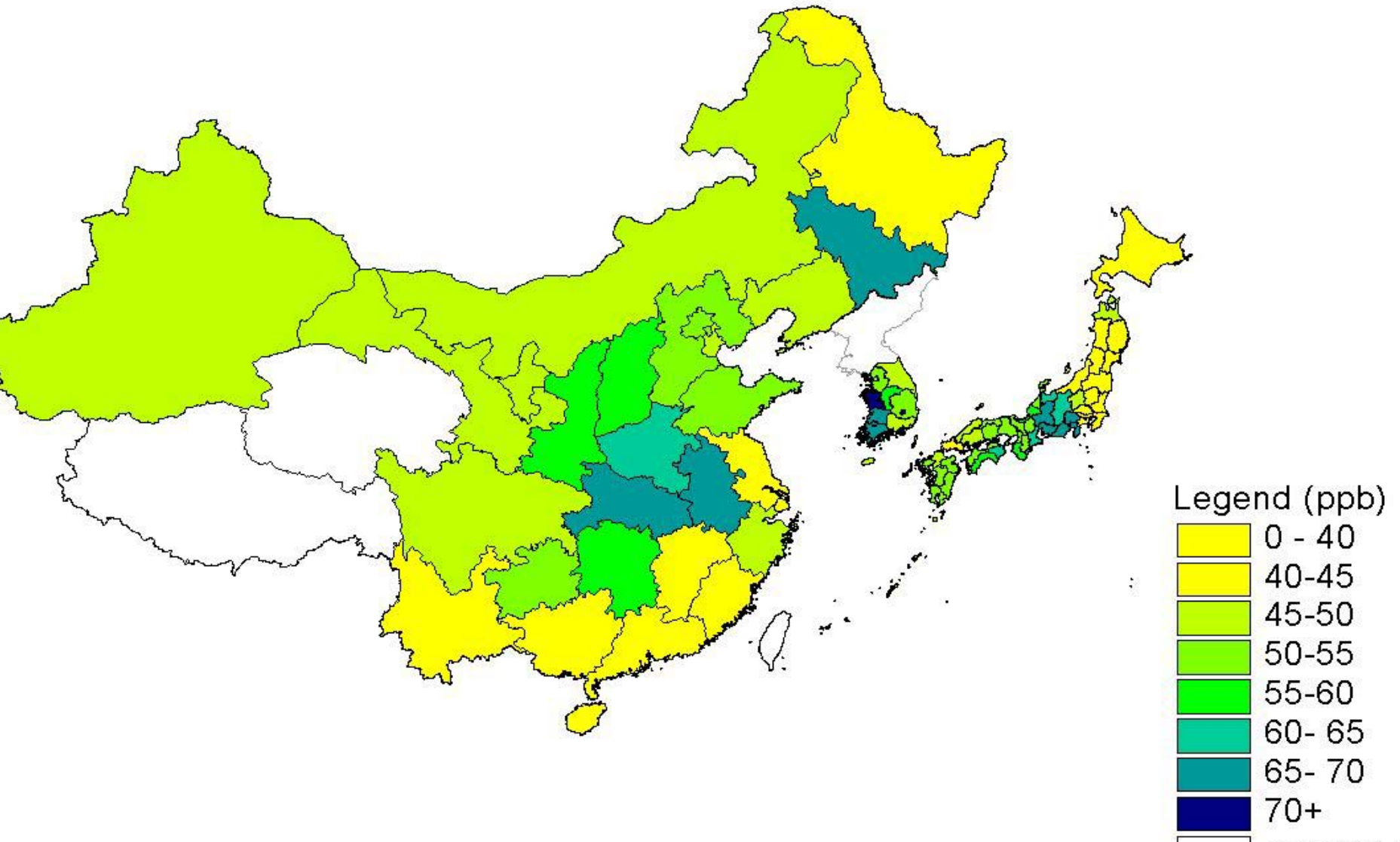
Spring Corn



Soybeans



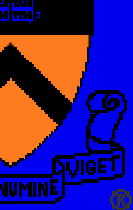
# 7-h Mean Exposure Distribution for Rice in East Asia





## Relative Yield Loss (%) in 1990

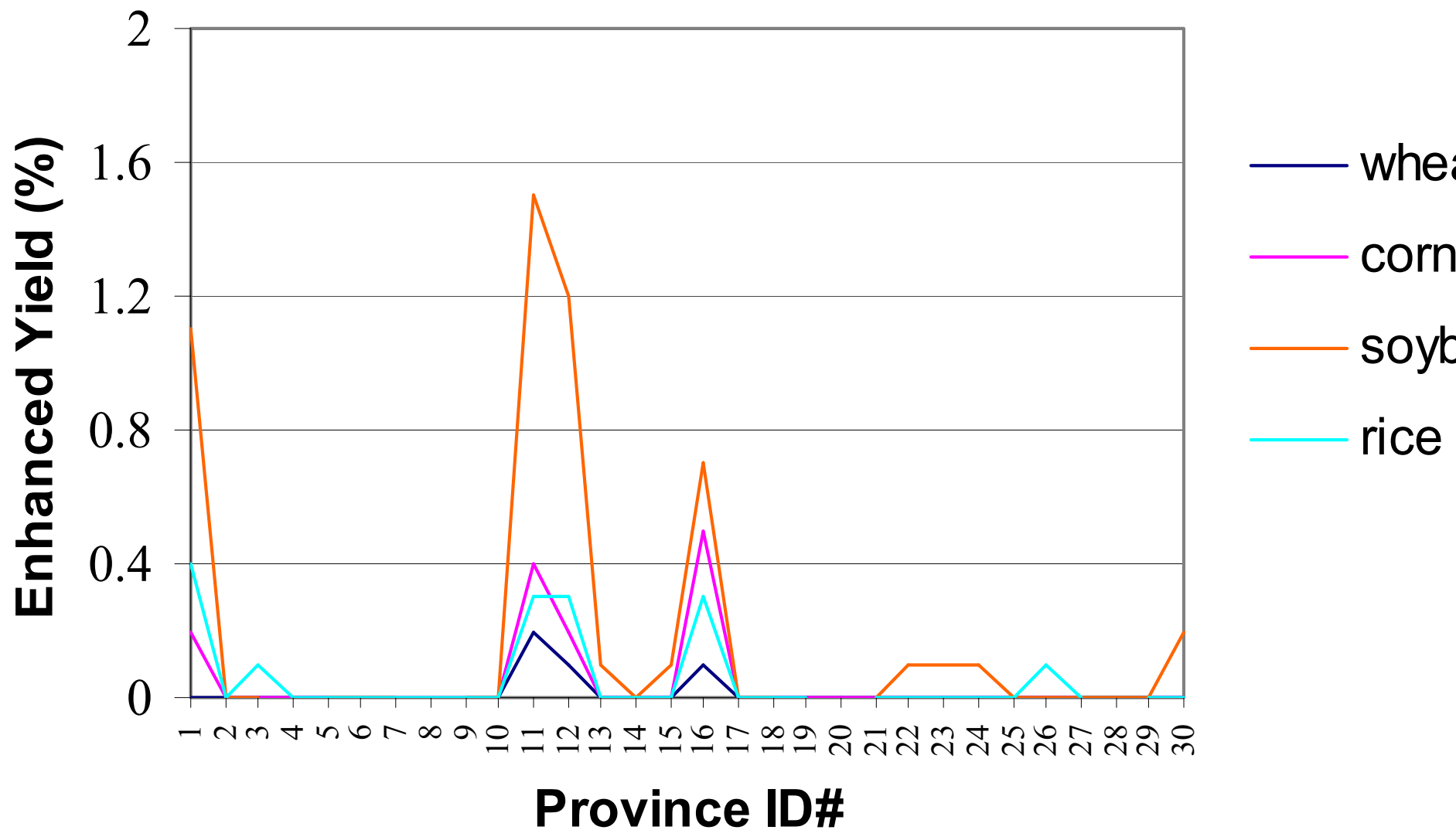
	China	Japan	Korea
Winter Wheat	1.9	0.2	17.8
Spring Wheat	0	0.1	-
Rice	2.3-3.8	2.4	2.9
Spring Corn	0.2		6.8
Summer Corn	0.3		
Soybeans	3.9	5	38.7



# Physical Yield Loss and Economic Damage in 1990

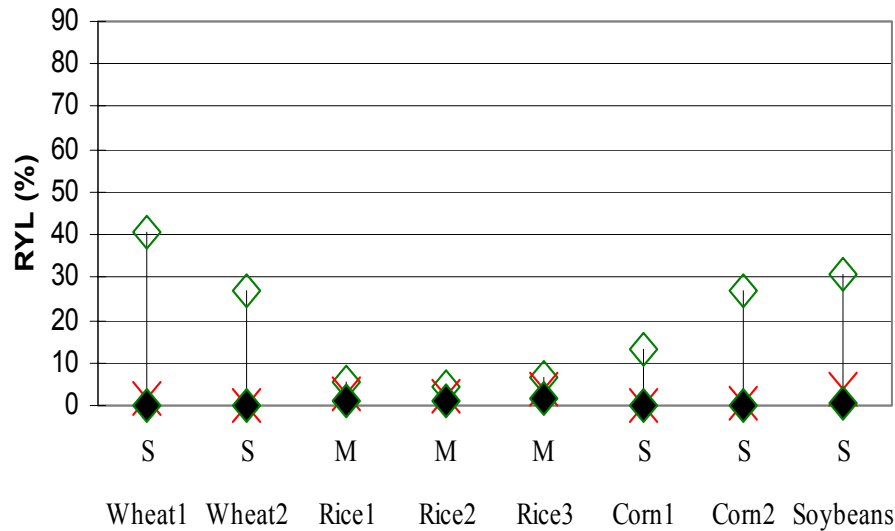
		<b>PYL (kton)</b>	<b>ED (\$ million)</b>
<b>China</b>	Winter Wheat	1,696	303
	Rice (7-h mean)	5,996	421
	Corn	271	23
	Soybeans	448	86
<b>Sub_total</b>		<b>8,411</b>	<b>833</b>
<b>Japan</b>	Wheat	8	
	Rice (7-h mean)	1,286	
	Soybeans	24	
<b>Sub_total</b>		<b>1,318</b>	
<b>Korea</b>	Wheat	0	
	Rice (7-h mean)	161	
	Corn	6	
	Soybeans	116	
<b>Sub_total</b>		<b>283</b>	

# Yield Increase after Compliance With the Class II O3 Standard (75ppb) in China in 1990

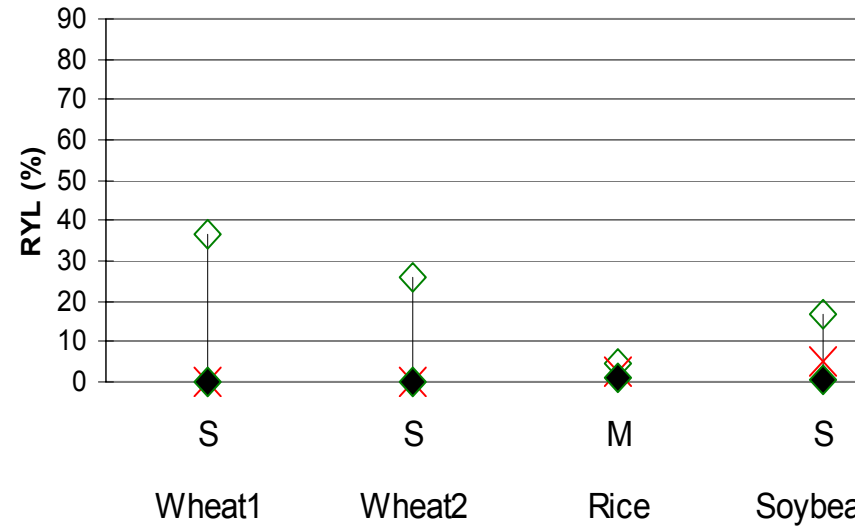


# Sensitivity of RYL to $\pm 25\%$ O<sub>3</sub> Change in 1990

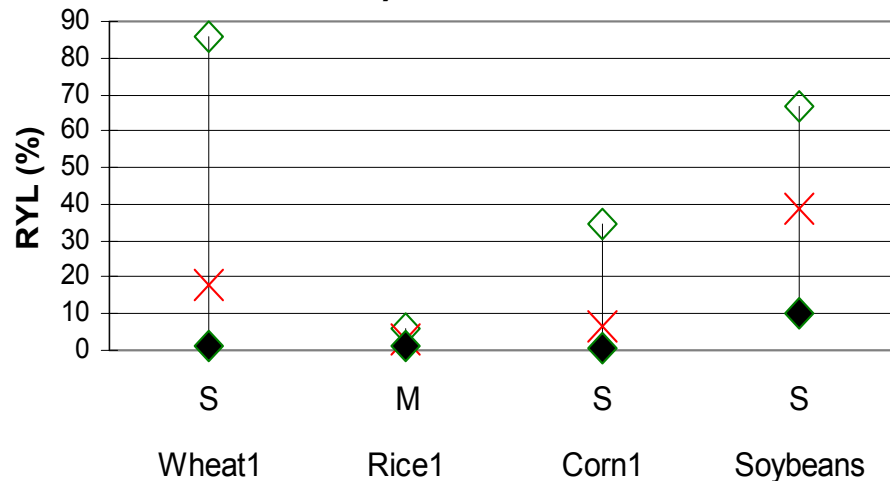
a) China



b) Japan



c) Korea



Wheat1=Winter Wheat

Wheat2=Spring Wheat

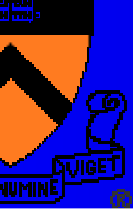
Rice1= Single-Crop Rice

Rice2= Double-Crop Early Rice

Rice3= Double-Crop Late Rice

Corn1= Spring Corn

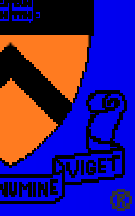
Corn2= Summer Corn



# Conclusions

- A cumulative exposure standard to protect crops and other plants is preferable to a peak-concentration standard.
- Agricultural yield loss caused by surface  $O_3$  in 1990:
  - <5% for grain crops in China and Japan
  - 3% (rice) - 40% (soybeans) in Korea
- Possible future increases in  $O_3$  concentrations could cause major reductions in agricultural yields throughout East Asia.
- More research is needed on the impact of  $O_3$  on crop cultivars used in developing countries.
- Although economic value of crops lost is not large, a desire for independence from food imports may encourage China to control its air pollution and hence its greenhouse gas emissions.





# Acknowledgements

- Xiaoping Wang, Princeton University
- Larry Horowitz, Geophysical Fluid Dynamics Lab